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The Effect of Load Position on Biomechanical and Physiological Measures during a Short Duration March

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Summary

This project attempted to determine the physiological and biomechanical effects of varying the centre of gravity of a load in a backpack in a short duration activity. Experienced soldiers (n=22) carried a 36.0 kg modified US Army ALICE backpack on a treadmill at 5.6 km/h for 15 minutes at 0° elevation. The subjects carried the load in three locations in a backpack (a high, middle and low distribution) and employed a load carriage vest as an 'alternative' distribution. This 'alternative' distribution balanced the load on the front and back of the subject. Oxygen consumption results showed no statistically significant difference between load locations ($P = 0.621$). Biomechanical analysis of the trunk lean and minimum included hip angles indicated significant differences between all 'alternative' comparisons as well as between the low and high load locations ($P < 0.05$). Maximum knee flexion angles were also shown to be significantly different between the low and alternate conditions. Cadence, stride length and displacement of the body COG did not show significant differences between conditions. Subjective evaluation indicated a strong preference for the alternative load condition due to the overall increased mobility and decreased feeling of discomfort. Under the conditions tested in this study it was concluded that load location does not significantly affect oxygen consumption but had a large impact on the perception of each load trial. A longer duration activity that imposes a larger strain on the subjects would be required to confirm this oxygen cost finding. The effect that trunk lean and the flexion angles will have on fatigue and energy consumption in a long-term exercise scenario has not been determined but should be undertaken in future studies. The subjective impact on the subjects should be considered as highly important and should therefore have an impact on the future design of load carriage systems.

Introduction

In order to make military personnel more effective they must reach their destination in the least possible fatigued state. Unfortunately, standard military loads are often 30 - 50 kg of rations, ammunitions and personal weapon. An objective set out by the Canadian Department of National Defence during the creation of the Integrated Protective Clothing and Equipment (IPCE) program was that analyses should focus on minimizing strain and pressures on the soldier while maintaining posture and freedom of gait (9).

Many studies have suggested that the logical choice for the load location would be closest to the body and to the body's centre of gravity (COG) as possible. This placement would reduce the excess moments about the body's COG and thus reduce the energy required to carry the load (1, 7). Other studies have shown that the use of a double pack, which carries half of the load on the front of the body and half of the load on the back, elicits a lower physiological cost (2, 7). Some studies of double packs as well as load carriage vests have shown that the Rating of Perceived Exertion (RPE) and heat stress increased when using these carrying methods, due to lack of ventilation. Another handicap associated with double packs and load carriage vests was the increase in task performance time when compared to the standard backpack due to encumbered movements (5, 7) and changes in gait pattern (6). Most physiologically based studies related to load

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placement or pack design were not sufficiently sensitive to pack COG locations. However, subjective responses to perceived comfort often provided additional insight into optimal load location when loads are carried on the back.

Many studies exist that examine either the biomechanics or the physiological effects of load carriage (3, 4, 8). While it is easier to examine either factor in exclusivity, those types of studies ignore the fact that the variables interact and are not mutually exclusive. Additionally, when only one modality is tested, it restricts the comparability of the study to others. One is unable to discern whether the biomechanical studies are eliciting the same physiological results that the physiological studies are, and vice versa. Only when studies use both modalities and a complete analysis of both factors, can one have a clearer, overall picture of the effects of load carriage on the carrier.

Materials and Methods

Twenty-two male subjects were recruited from the 1st Canadian Division Headquarters Signals Regiment from CFB Kingston. Each subject participated in four load trials in which 36 kg was carried in different locations. Three trials used a modified ALICE pack made by the US Army Natick Research Lab, which allowed for the alteration of the COG to high, middle and low locations spread by 13.3 cm each (Figure 1). The fourth trial used an alternative weight distribution system composed of a Velcro™ covered load carriage vest, upon which 18.0 kg was carried on the front, and 18.0 kg on the back. Each trial was 15 minutes in duration and consisted of a level treadmill walk at 5.6 km/h.

(i) (ii)

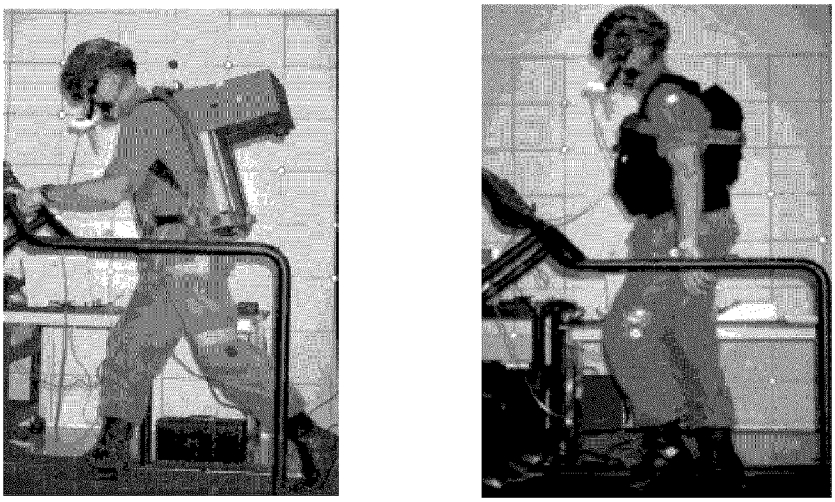

Figure 1. Load carriage systems used for human trials
(i) Backpack by US Army Natick Research Lab;
(ii) Load carriage vest by Pacific Safety Products Inc.

Oxygen consumption was measured using a portable metabolic cart (TEEM 100). For analysis, the last five minutes of steady state oxygen consumption was averaged and analyzed. For the kinematic analysis, joint markers were placed on the subjects at the 5th metatarsal, calcaneous, lateral maleolus, knee, greater trochanter and the shoulder. Using this set-up, we examined the joint angles at the knee and hip, their cadence, stride length, and the motion of the centre of mass of the subject during the gait cycle. It was hypothesized that there would be a significant difference between the alternate and other distributions since it was thought that the alternate would lead to a more normal gait pattern.

The subjects also completed subjective evaluations of the load location after each loaded trial. The questionnaire asked about overall acceptability, balance, thermal comfort, load control, and physical comfort (Table 1). It was hypothesised that subjects would rate the alternative load carriage system most acceptable due to its balanced load distribution. Conversely, the low load location was hypothesised to be ranked lowest due to the necessity for subjects to bend farther forward in order to bring the COG of the pack over the body's COG. A follow-up questionnaire was also administered to gather ratings of the load locations from worst (1) to best (4) for the four conditions.

Table 1. Questions asked on the post-test questionnaire – subjects answered these questions based on a 6 point rating scale from 1 (totally unacceptable) to 6 (totally acceptable)

	Question
1	Rate the overall acceptability of load position for marching
2	Rate your marching balance
3	Rate your load control ability
4	Rate your ease of mobility in marching order
5	Rate your level of physical comfort when marching
6	Was the load in a good position?
7	Would you be comfortable marching with your load in this position?
8	Rate your level of thermal comfort when marching

Results

The results of this study are summarized in Table 2. Oxygen consumption levels across load distributions were not significantly different. Results from the kinematic analysis indicated that significant differences existed between trunk lean angles, minimum included hip angles, and maximum knee angles. In all significant comparisons, the alternate position was one of the significantly different pairs. The maximum knee angle in the low position was significantly lower than the alternate position. The trunk lean and minimum hip angle were also significantly different with the same pattern of post hoc differences – the alternate condition was significantly lower than all other conditions in addition to the high condition being significantly lower than the low condition. Stride length, cadence and the displacement of the body's COG were not significantly different between load distributions.

Table 2. Measured variables and their significance levels including the conditions that exhibited the differences.

Measured Variable	p-Value	Post Hoc Differences
Oxygen Consumption	$P > 0.05$	None
Cadence	$p > 0.05$	None
Stride Length	$p > 0.05$	None
Displacement of Body COG	$p > 0.05$	None
Maximum Knee Angle	$p < 0.05$	Low < Alternate
Trunk Lean Angle	$p < 0.05$	Alternate < Low, Middle, High High < Low
Minimum Included Hip Angle	$p < 0.05$	Alternate < Low, Middle, High High < Low

Results from the initial questionnaire showed that the low pack position ranked least acceptable in 7 out of 8 categories that were examined. The alternate configuration ranked most acceptable in all categories except thermal comfort, where it was rated least acceptable (Figure 2). The follow-up questionnaire results showed that subjects disliked the low load configuration due to the extreme lean required, and this created undue stress on the back. The follow-up questionnaire also showed that the alternative load distribution was not ideal, as it constricted the chest, resulting in laboured breathing. The differences in overall preference were statistically significant ($p < 0.05$). Post hoc simultaneous statistical inference showed that significant differences existed between all paired configurations except high and alternative. Results also showed that 91% of subjects ranked the low load configuration as last or second to last choice with the most common reported problem identified as excessive body lean and undue stress on the lower back.

Discussion

There was no significant difference in the repeated measures ANOVA between load locations and oxygen consumption under the conditions that were tested in this experiment (Table 2). This result agreed with the study performed by Bobet and Norman (1), which reported that there was no discernible difference in energy cost (as extrapolated from heart rate) based on varying the location of the COG over a 90 m walkway at 5.6 km/h while carrying a 19.5 kg pack. These results, however, disagreed with the results of Datta and Ramanathan (2) who reported that the double pack (a pack which places some of the load on the front of the body) proved less costly in terms of energy. Datta and Ramanathan stated that this double pack was more energy conservative than six other forms of load carriage including the standard backpack carrying 30 kg at 5 km/h for 20 minutes. Their experimental design, however, used a seven level paired-t test for analysis without an apparent compensation for the loss of efficacy when multiple t-tests are performed. This may have given an artificial significance, especially when the difference between oxygen consumption at the load locations was very small.

Trunk lean and included hip angles were significantly different between all three backpack locations and the 'alternate' configuration and between the low and high permutations. For a subject to maintain balance with the total load over the body's centre of gravity, trunk and total body leans are employed. Placing the load more vertically in line with the body's centre of gravity reduces the moment about the hips caused by the backward pull of the backpack. The alternate configuration reduced the backward moment by dividing the load between the front and back of the subject. With this distribution, the line of action of the force caused by the load then passes close to the centre of gravity of the body, reducing the rotary moment that the load exerts. In a similar vane, a lower included hip angle would indicate a more upright gait. Bobet and Norman (2) clarified that in general, loads placed higher than the body's centre of gravity cause a larger forward moment. Placement of the load below the COG causes a larger backward moment. Movement of the load over the body's COG allows for the line of action of the load to fall in the same line as the body's mass and, therefore, will reduce the muscle effort required to counter the load moments. This explains why the subject is in the most stable position for standing. However, this explanation falters when locomotion is considered, where the COG must be placed in front of the feet for forward motion. In this condition, a low COG is poorest since the subject must use trunk lean to move the COG in front of the feet. In terms of the knee angle, a higher knee angle is indicative of more normal gait. In this study, the low condition had knee angles that were significantly lower knee angles indicating a change from normal that is likely a form of compensation for the load and its distribution. Compared to baseline values, the subjects employed a shorter stride length and increased cadence while under load-carrying conditions. There were no differences between load conditions and stride length, cadence, or displacement of the COG.

The subjective responses from both the initial and follow-up questionnaires indicated that the lower the load placement, the poorer the subjects rank overall acceptability. Subjects reported that this lower load placement caused them to lean farther forward. This excess lean resulted in soreness of postural and neck muscles that are required to be constantly active in order to lean forward yet hyperextend the neck to see forward. There is a postural benefit to carrying the load higher. As discussed above, the higher the load was placed, the closer to baseline were the trunk lean and included hip angles. However, when the load was placed at the high end of the backpack, load stability decreased, which would make it unsuitable for uneven

terrain. This may have increased muscular activity in the shoulder area during gait thus not reducing shoulder discomfort as much as expected. Both lean angles were significantly greater than the angles that were recorded when the load was balanced on the front and the back. The benefits of carrying the load balanced on the front and back are better manoeuverability and a reduction in back stresses. The downside of the alternative method was little or no skin-air circulation, leading to thermal discomfort. The follow-up questionnaire asked the subjects to rank the load locations from best to worst on a scale of one to four. Using these results, an overall ranking of the four load locations was possible. The responses indicated that the alternate configuration was the most preferred followed by the high middle and low placements in that order.

The relative importance of physiological, biomechanical or subjective variables is not known. For example, in selecting between high and alternative positions, a determination must be made about which factor is more important: manoeuvrability or thermal comfort. Future research should be directed toward development of a weighting factor for each family of tests to determine their relative importance to the subjects. For the military, this might involve tradeoffs related to "soldier effectiveness" while for recreational backpackers individual preferences might be the deciding factor. All else being equal, however, subjective evaluation should be viewed as very important in the overall effect of load location.

Under the conditions tested in this study there was no significant difference in oxygen consumption based on load location. However, since this non-significant result is contested in the literature, a longer activity duration that would impose a larger strain on the subjects might accentuate differences to a greater extent. Trunk lean, included hip and knee angles vary significantly with load location. A lower load placement increases trunk angle and decreases included hip and maximum knee angle. These statistically significant differences indicate that having the load distributed across the front and back of the body will lead to a more normal and upright gait. The effect that these lean angles will have on fatigue and energy consumption in a long-term exercise scenario has not been determined but should be undertaken in future studies.

This study has attempted to provide an integrated look at the effects of load location in a backpack. It is apparent that one cannot look at only one factor in the evaluation of a backpack or loading strategy. Subjective responses, for instance, may be able to distinguish differences between strategies that modern instrumentation may not be able to quantify. This does not suggest that backpack design rely solely on subjective information, but that it is used in combination with other empirical measures.

Acknowledgements

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